REPORT No. 261

RESISTANCE AND COOLING POWER OF VARIOUS RADIATORS

By R. H. SMITH
Aerodynamical Laboratory, Bureau of Construction and Repair,
United States Navy

REPORT No. 261

RESISTANCE AND COOLING POWER OF VARIOUS RADIATORS

By R. H. Smith

INTRODUCTION

This report combines the wind-tunnel results of radiator tests made at the Navy Aerodynamical Laboratory in Washington during the summers of 1921, 1925, and 1926, and submitted for publication to the National Advisory Committee for Aeronautics, November 29, 1926. In all, 13 radiators of various types and capacities were given complete tests for figure of merit. Twelve of these were tested for resistance to water flow and a fourteenth radiator was tested for air resistance alone, its heat-dissipating capacity being known. All the tests were conducted in the 8 by 8 foot tunnel, or in its 4 by 8 foot restriction, by the writer and under conditions as nearly the same as possible. That is to say, as far as possible, the general arrangement and condition of the apparatus, the observation intervals, the ratio of water flow per unit of cooling surface, the differential temperatures, and the air speeds were the same for all. Also, for reasons of comparison, the L/D value of 6, which was assumed in the 1921 tests as the L/D of the airplane using the radiator, was also used in the more recent tests.

No attempt is made to enter upon the theory of heat dissipation. Only the actual test results are given and reduced to coefficient form. The precision of the tests as representative of full-flight performance is definitely known only in the case of the *HN-2*. The McCook Field full-flight performance and the Navy tunnel performance of this radiator agree within about 3 per cent.

Since this full-flight test was made with unusual care and since the wind-tunnel tests on all the radiators were made not only accurately but also at almost full scale, it would seem probable that these tests represent quite accurately the full-flight performances in actual service.

DESCRIPTION OF RADIATORS

Nine radiators of the 13 had cores of the cartridge type whose frontal areas were uniformly 1 foot square. Figure 1 gives the external appearance of one of these radiators and Figures 2 and 3 are close views of core segments of each. Six of these 9 are known as G. and O., 2 as U. S. Cartridge, and 1 as Rome Turney. For the heat-dissipation tests each was equipped with headers of equal frontal area.

With these nine was tested a tenth radiator, known as the Lamblin, composed of evenly spaced radial planes, whose outline was roughly that of a spheroid. The air flowing along the major axis entered at the front end and passed out between the planes. Stream-lined hoops, placed at the front and back, served as water headers as well as strengthening members. Structural data for this radiator as well as for the first nine are given in Table I.

The other three radiators tested for figure of merit were manufactured by the Heinrich Engineering Corporation. One, known as type *HN-2* and illustrated in Figure 4, consisted of 230 flat parallel fins three-eighths inch apart, each composed of tubes of 0.007 inch hard drawn copper, flattened to about 0.50 inch by 0.07 inch and tack soldered edge to edge. These fins were supported and connected with the main headers by thin branch headers into which the flat tubes of the fins emptied. At the leading edge there was a shutter so constructed as to fold into the streamline form of the headers when closed, as in the figure, or to spread over the ends of the fins when open. The approximate external dimensions of this radiator are 30 inches length, 44 inches height, and 9 inches width. It contained about 206 square feet of radiating surface and had empty and full weights of 113 and 173 pounds, respectively.

The other two Heinrich radiators, known as the Heinrich wing radiators, are illustrated in Figures 5 and 6. They consisted of several thin fins extending vertically from the under surface of the wing, each constructed in similar fashion and of like material to those used in the Heinrich stream-line radiator described above. The over-all dimensions of the wing radiator fin was 5 inches width and 31.75 inches length. The two wing radiators differed only in the spacing and the number of the fins; one had 9 fins spaced 1 inch, the other 6, spaced 1.5 inches. Both were attached to a 40 by 36 inch wing of R3C3 section.

The fourteenth radiator, which was tested for air resistance alone, was a Curtis radiator having a 9-inch cartridge core and over-all dimensions of 40 by 12 by 10.75 inches. This radiator is illustrated by Figure 7. Its full and empty weights were 159.8 and 105.6 pounds, respectively.

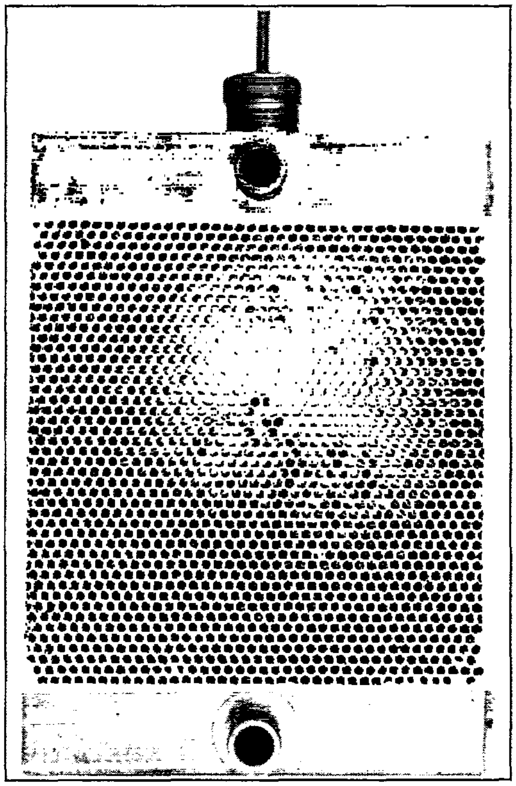


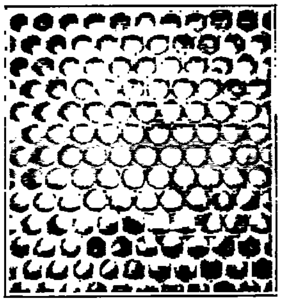
FIG. 1.—Typical test radiator

METHOD OF MEASURING AIR RESISTANCE

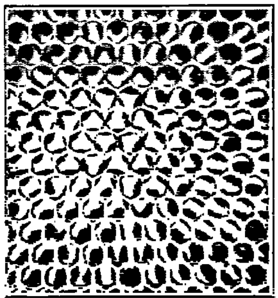
The air resistance of the radiator or radiator core was determined, in most cases, by suspending it by two or more wires attached to its upper edges and running either to the tunnel, ceiling, or through it to the ceiling of the laboratory above. The radiator was then displaced downstream until the displacing force exceeded the maximum air resistance to be measured, then connected to the balance shank by a horizontal tension wire. Lateral motion of the radiator was prevented by two taut cross-tunnel wires with eyelets through which two guide pins, projecting upstream from the upper and lower edges of the radiator, had only slight lateral freedom. The downstream movement of the radiator due to the wind was negligible, hence no correction of the measured resistance for gravity was required. To determine the correction required to reduce the measured resistance by the resistance of the suspending wires, a second run was made with double wires, the additional wires being placed beside the permanent ones and 10 or more diameters away. The increments of resistance thus found, due to the additional wires, was taken as the resistance of the permanent ones and was subtracted from the radiator and single-wire resistance as the wire correction. The resistance of the horizontal wire was negligible.

Figures 7 and 8 illustrate the Curtis radiator mounted in the tunnel ready for an air-resistance test. All the radiators or radiator cores were tested for air resistance in a similar manner excepting the two wing radiators, for which the method of mounting was necessarily a little different.

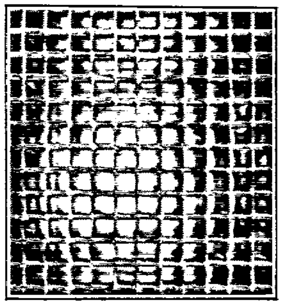
The two Heinrich wing radiators were given air-resistance tests assembled to a wing segment. This wing segment was supported in the inverted position at zero degrees angle of attack by four vertical suspension wires, as shown in Figure 5. The wing was restrained from downstream movement in the wind by a compression rod running horizontally from the balance shank to the trailing edge of the wing, and from lateral motion by cross-tunnel wires, both vertical and



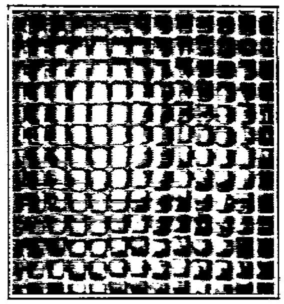
9-inch U. S. Cartridge



4-inch U. S. Cartridge

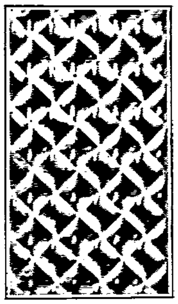


5-inch G. & O. 176503

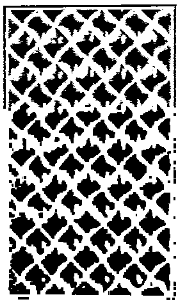


5-inch Rome Turney

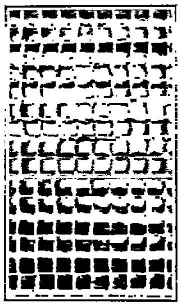
FIG. 2.—Radiator cores



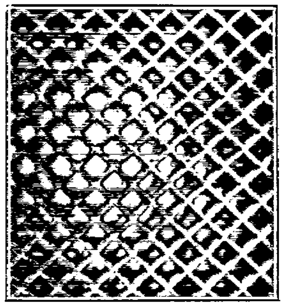
2-inch G. & O. 176506



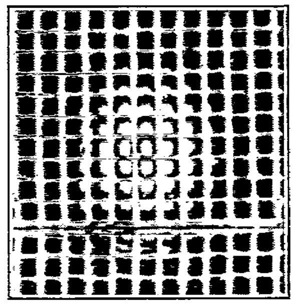
2-inch G. & O. 176505



3-inch G. & O. 176507



5-inch G. & O. 176502



5-inch G. & O. 176504

FIG. 3.—Radiator cores

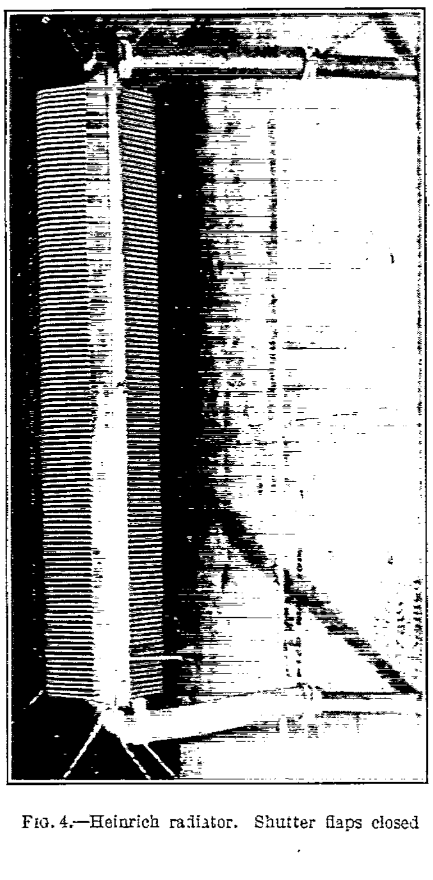


FIG. 4.—Heinrich radiator. Shutter flaps closed

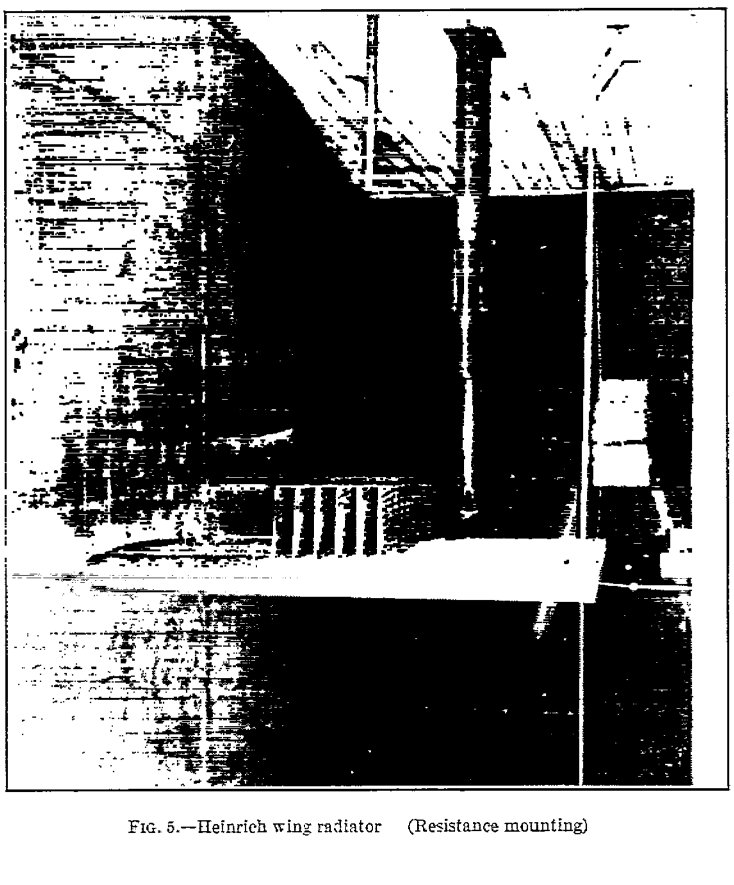


FIG. 5.—Heinrich wing radiator (Resistance mounting)

horizontal, with eyelets at the intersections, through which guide pins, projecting from the leading edge of the wing had only small lateral or vertical freedom. The wing lift, being downward, was borne by the four suspension wires, the drag by the compression rod and the balance shank. The resistance of the radiator was determined from two tests, one made on the radiator and wing assembled as in Figure 5 and the other made on the wing alone. The difference of the resistances was taken as the radiator resistance.

METHOD OF MEASURING RATE OF COOLING

The general appearance of the apparatus for a cooling test is portrayed in Figure 9. The radiator was supported symmetrically in the tunnel throat by 8 taut stay wires, 4 at the top running obliquely up to the tunnel ceiling and 4 at the bottom running obliquely down to the tunnel floor. Hot water pumped from the supply tank, shown to the right, was passed through the Venturi meter, thence through the radiator and the return pipe to the same tank, which was kept at nearly constant temperature by means of a steam-heating coil. Thermometers which were accurately calibrated were carefully inserted to the same depth in the supply and return pipes to measure the temperature of the water upon entering and leaving the radiator, and a third was inserted through the wind-tunnel ceiling to measure the temperature of the general air stream. The rate of flow of the water through the radiator was measured with the standard Venturi. The speed of the undisturbed air approaching the radiator was measured in the usual way with a Pitot tube and manometer, the Pitot tube being placed sufficiently upstream to avoid blanketing by the radiator. The manometer and Pitot tube in this position were calibrated to read the air speeds in the position occupied by the radiator.

MEASUREMENT OF WATER PRESSURE-DROP INSIDE RADIATORS

The pressure difference of the water on entering and leaving the radiator due to various rates of flow was measured by two U-tube manometers, one in each header.

RESULTS OF THE TESTS

Tables I to V, inclusive, show, for the various air speeds noted, the heat dissipation and air resistance, both as measured and in coefficient form, and the ratio of the two expressed in terms of power, which is defined as the figure of merit. Table I contains the results of 13 tests on 10 radiators—the Lamblin radiator was tested at four rates of water flow—the data given for each test being condensed from data as observed and recorded in Tables II, III, and IV. These latter three tables give the data in uncondensed form on the three Heinrich radiators. The six observations for each air speed were taken at two-minute intervals after fairly steady air speed and water flow were obtained and thermal equilibrium was established. Each observation given in Table I is the average of six like observations. Various definitions, constants, and radiator dimensions are supplied in the tables.

The air resistance of the radiators or the radiator cores, as given in the five tables and plotted in Figures 10, 11, and 12 is expressed by the general equation $R=KV^n$ where n varies from 1.84 for the Heinrich wing radiators to 2.13 for the Heinrich stream-line radiator. For the cartridge core types n varies from 1.95 to 2.02.

The figure of merit, which is the final object of the tests, diminishes continuously with increase of velocity. For the cartridge core types the figure of merit decreases roughly with the increase of the velocity squared, while for the wing radiator types it decreases nearly with the increase of the velocity. In the case of the cartridge core types the short tube radiators have greatest merit at low speeds, the long ones at high speeds. This is clearly shown by the U. S. Cartridge radiator with 9-inch tubes. This radiator has the least merit of the nine at low speeds, but is the most efficient at speeds above 130 miles per hour. The figure of merit of the parallel fin type radiator, such as the Heinrich wing radiators, is about the same as that of the best cartridge core at airplane landing speeds, but is distinctly better at the higher air speeds. Figure of merit plots are given in Figures 13, 14, and 15.

The pressure heads required to maintain different mass rates of water flow through the various radiators are given in Tables VI and VII and are plotted in Figures 16 and 17 for all 13 radiators except the Heinrich stream-line radiator, upon which these measurements were omitted. The pressure heads have the general form $p = K v^n$ where, for all cases measured, n varies from 1.86 to 2.00. The formula for pressure drop in terms of turbulent flow speed, commonly given in works on fluid dynamics, is $p = Kv^{2.00}$.

The tables and diagrams given in this report may be analyzed in different ways, depending upon the experimental facts desired. No attempt is made here to enter upon such analyses, although the material is presented in a form as complete as possible for this purpose. Likewise no expression of opinion is given touching the suitability of any radiator or type of radiator for any particular use.

REFERENCES

DICKINSON, H. C.; JAMES, W. S.; and KLEINSCHMIDT, R. V. General analysis of airplane radiator problems. National Advisory Committee for Aeronautics. Technical Report No. 59, 1920. (A useful reference for definitions.)

DICKINSON, H. C.; JAMES, W. S.; and KLEINSCHMIDT, R. V. General discussion of test methods for radiators. National Advisory Committee for Aeronautics. Technical Report No. 60, 1920. (A good account of the technique, laboratory apparatus, and working formula used in a thorough radiator test at ground pressure.)

DICKINSON, H. C.; JAMES, W. S.; and KLEINSCHMIDT, H. C. Heat dissipation and other properties of radiators. National Advisory Committee for Aeronautics. Technical Report No. 63, 1920. (This reference considers how the head resistance and the heat transfer of a radiator are affected by such items as air speed, type of core, and rate of water flow.)

HARPER (3d), D. R., and BROWN, W. B. Mathematical equations for heat conduction in fins of air-cooled engines. National Advisory Committee for Aeronautics. Technical Report No. 158, 1923. (This report gives the mathematics required in a theoretical treatment of heat flow.)

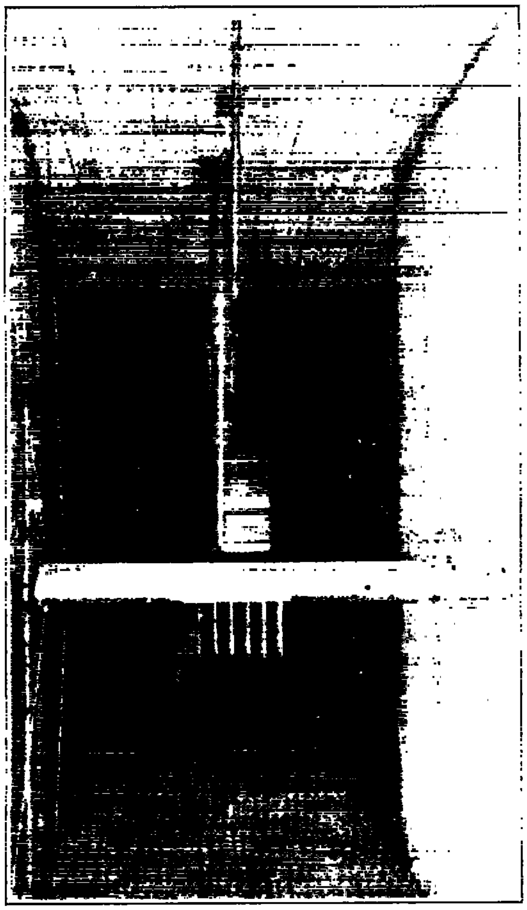


FIG. 6.—Heinrich wing radiator. (Heat dissipation mounting)

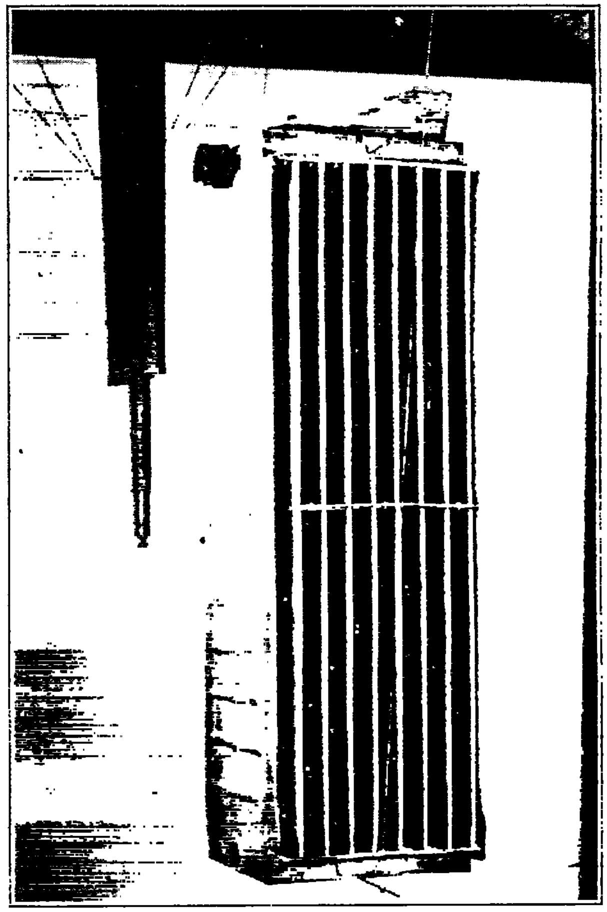


FIG. 7.—Curtiss radiator. Shutter open

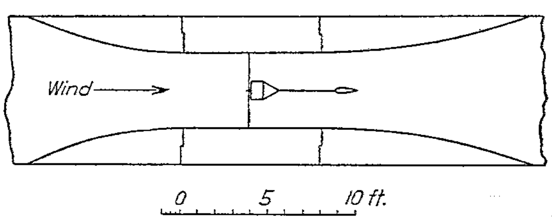


FIG. 8.—Plan view of 4 by 8 foot wind tunnel and radiator mounting

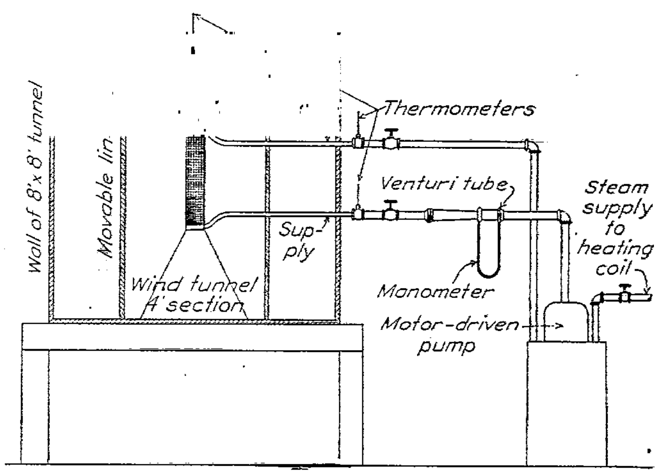


FIG. 9.—Apparatus for thermal test of radiators

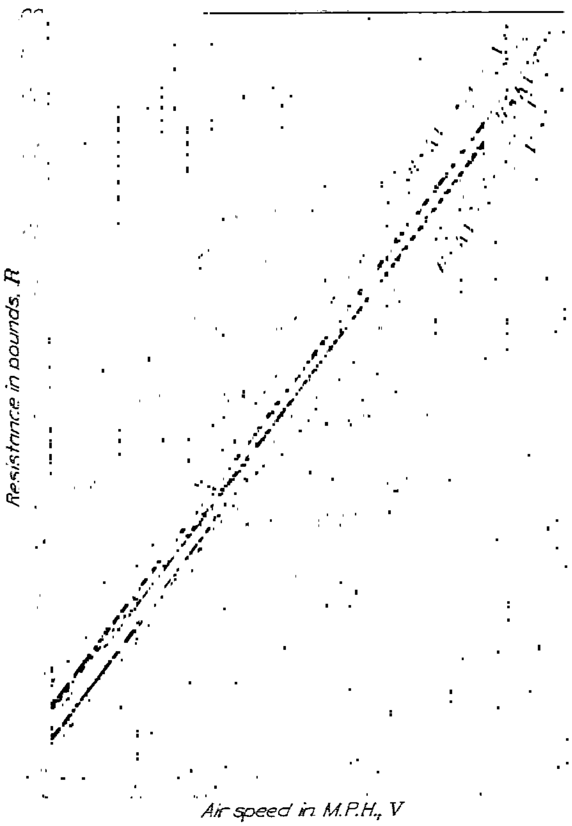


FIG. 10.—Resistance of radiator cores in pounds per square foot frontal area

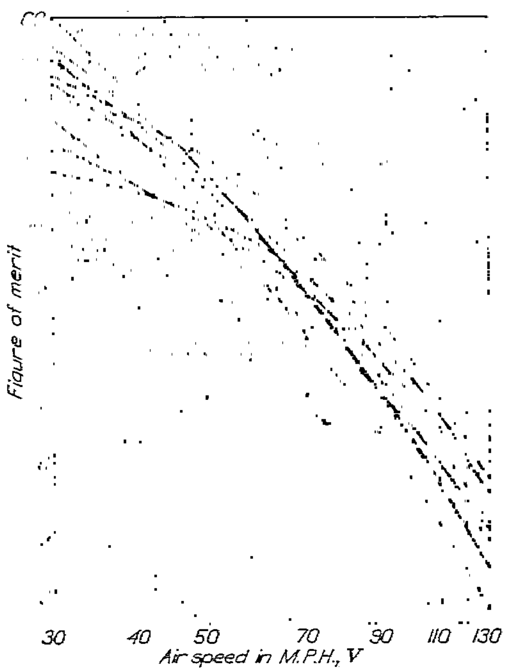


FIG. 13.—Figure of merit versus air speed for various radiator cores

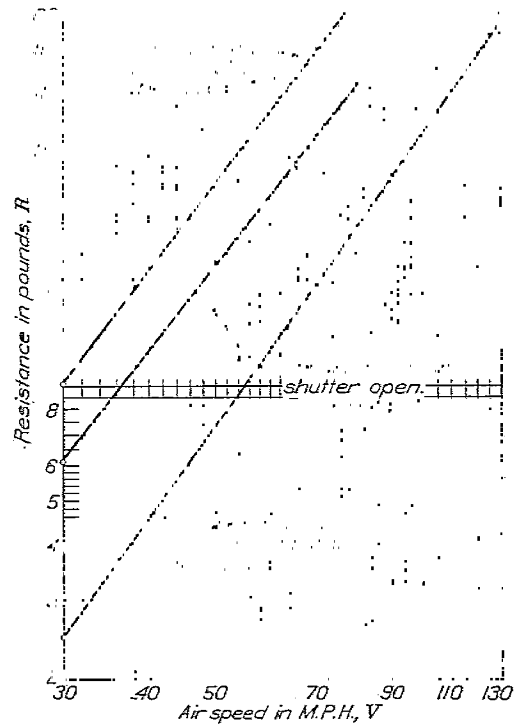


FIG. 11.—Resistance versus air speed of Heinrich and Curtiss radiators

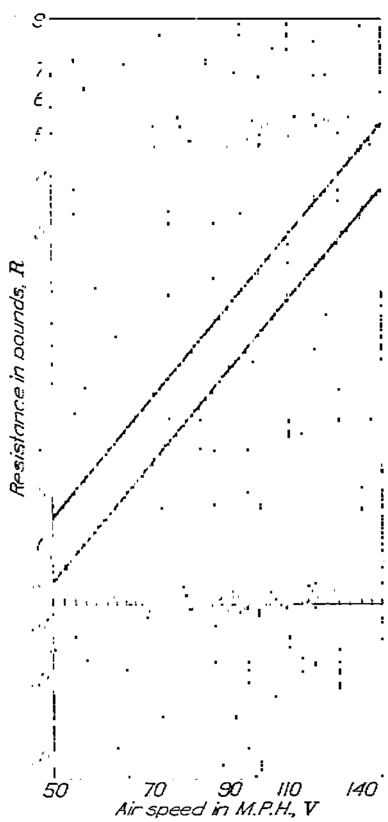


FIG. 12.—Resistance versus air speed of Heinrich wing radiators

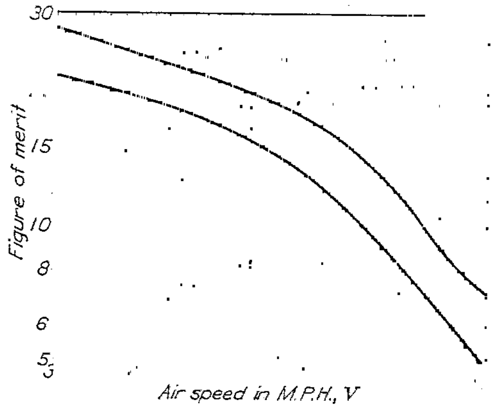


FIG. 14.—Figure of merit versus air speed for Heinrich and Curtiss radiators

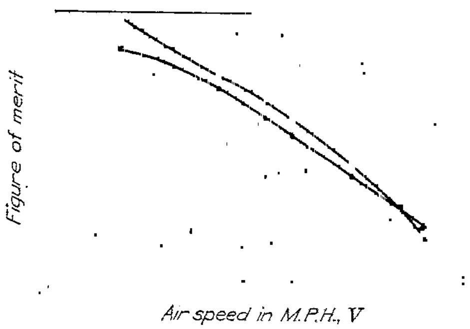


FIG. 15.—Figure of merit versus air speed for Heinrich wing radiator

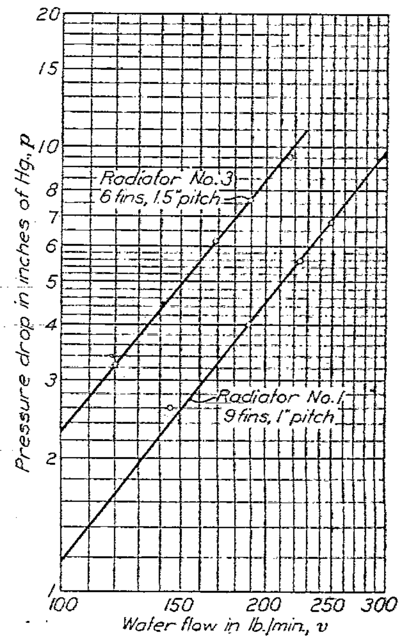


FIG. 17.—Pressure drop versus water flow for Heinrich wing radiator

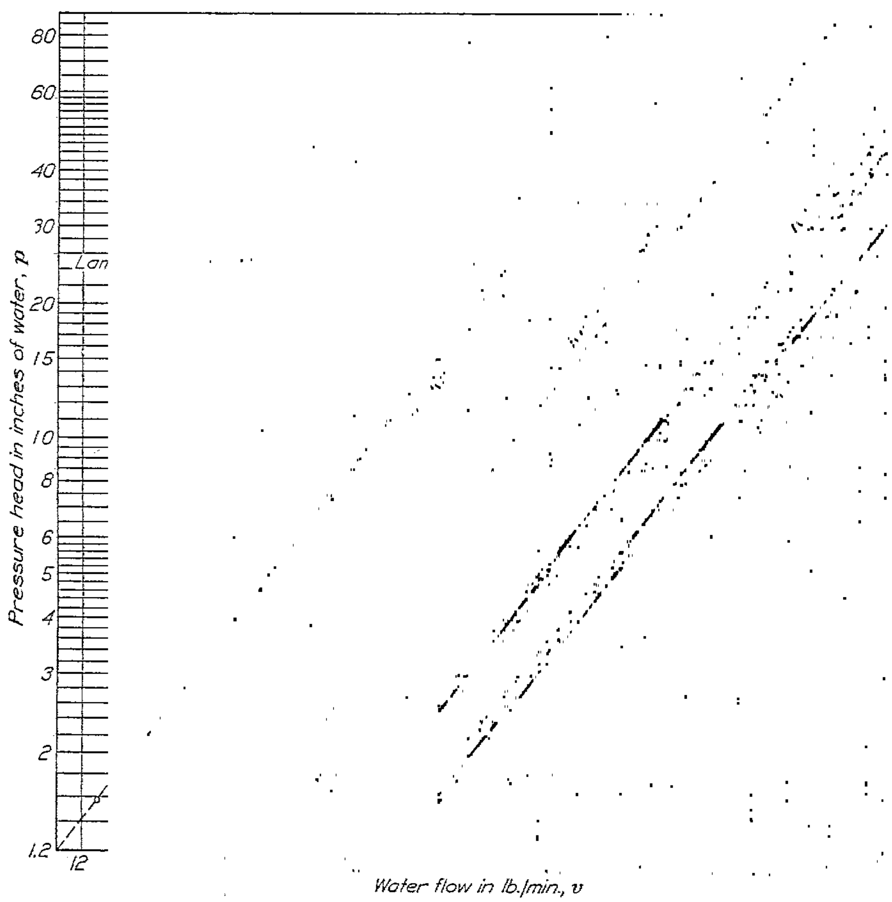


FIG. 16.—Pressure head versus water flow for various radiators

TABLE I.—FIGURE OF MERIT

Name of radiator with miscellaneous data [1]	Air speed M. P. H.	Temperature in degrees F.							B. t. u. dissipated per minute for 1 square foot frontal area of core only = C [2]	C per 100° difference between mean water and air	Total resistance of radiator core, in pounds	Total resistance per square foot of frontal area = R	HP. dissipated per 100° difference of temperature per square foot of frontal area = H	HP. absorbed per square foot of frontal area = P	Figure of merit = H/P
		Air in tunnel	Water inlet	Water outlet	Mean	Difference	Mean difference, air and water	Rate of flow, pounds of water per minute							
9-inch U. S. Cartridge	30	97	185.5	178.5	182	7	85	101.5	687	808	1.635	1.635	18.97	0.706	26.88
W=43.17 pounds.	50	98	189.5	177	183.2	12.5	85.2	99.5	1,202	1,411	4.544	4.544	33.13	1.563	21.21
A=1.00 square foot.	70	101	184.5	168.5	176.5	16	75.5	98	1,515	2,008	8.927	8.927	47.15	3.007	15.67
D=3.35 per cent.	90	103	186	168	177	18	74	106	1,844	2,491	14.920	14.920	58.48	5.303	11.01
	110	106	184	165	174.5	19	68.5	104.5	1,919	2,800	22.120	22.120	65.74	8.591	7.65
	130	115	181.6	164	172.8	17.6	57.8	105	1,786	3,090	31.170	31.170	72.55	13.285	5.46
4-inch U. S. Cartridge	30	92	184.5	177	180.7	7.5	88.7	105.8	772	870	1.715	1.749	20.43	.422	48.41
W=21.25 pounds.	50	93.5	188	176.5	182.2	11.5	88.7	102.8	1,150	1,296	4.814	4.915	30.43	1.126	27.01
A=0.98 square foot.	70	96	182.5	169.5	176	13	80	107.5	1,358	1,697	9.567	9.758	39.85	2.480	16.06
D=4.76 per cent.	90	98	186.5	170.5	178.5	16	80.5	104.5	1,625	2,019	15,820	16,150	47.41	4.722	10.04
	110	104	179	164	171.5	15	67.5	105	1,530	2,267	23.820	24.310	53.23	8.163	6.52
	130	112	180.4	166	173.2	14.4	61.2	105	1,470	2,402	33.470	34.150	56.40	13.054	4.32
5-inch Rome Turney	30	96	183.5	177	180.2	6.5	84.2	106.7	671	797	1.485	1.485	18.71	.423	44.25
W=22.84 pounds.	50	97	182	172	177	10	80	105.2	1,018	1,273	4.094	4.094	29.89	1.053	28.38
A=1.00 square foot.	70	100	183	170	176.5	13	76.5	103.5	1,302	1,702	7.897	7.897	39.96	2.182	18.30
D=3.27 per cent.	90	104	183	169	176	14	72	105.5	1,429	1,984	12.900	12.900	46.58	4.008	11.62
	110	105	188.5	172.5	180.5	16	75.5	106.7	1,651	2,188	19.200	19.200	51.37	6.743	7.61
	130	113	186.8	172	179.4	14.8	66.4	105.2	1,506	2,270	26.570	26.570	53.30	10.520	5.07
5-inch G. & O. 176504	30	91	181.4	175	176.6	7.3	85.6	102.5	725	847	1.695	1.713	19.89	.467	42.58
W=24.77 pounds.	50	92.5	182	171.5	176.7	10.5	84.5	104	1,059	1,253	4.784	4.835	29.42	1.194	24.65
A=0.99 square feet.	70	96	175	163.5	169.2	11.5	73.3	106.8	1,191	1,625	9.447	9.54	38.16	2.55	14.96
D=3.98 per cent.	90	99	179.5	166	172.7	13.5	73.7	107	1,401	1,903	15.74	15.89	44.68	4.801	9.29
	110	103	181.5	167.5	174.5	14	71.5	103	1,399	1,955	23.52	23.75	45.9	8.171	5.62
	130	113	185	170	177.5	15	64.5	100	1,414	2,192	33.07	33.40	51.47	13	3.96
3-inch G. & O. 176507	30	100	184.5	178.5	181.5	60	81.5	102.5	595	730	1.675	1.675	17.14	.331	51.8
W=14.75 pounds.	50	101	189	180	184.5	9	83.5	103.8	904	1,082	4.504	4.594	25.41	.94	27.04
A=1.00 square foot.	70	102.5	187.4	177	182.2	10.4	79.7	104	1,046	1,312	8.977	8.977	30.81	2.133	14.44
D=3.22 per cent.	90	106.5	185	174	179.5	11	73	105	1,118	1,532	14.82	14.82	25.97	4.142	8.68
	110	111	187.2	175.5	181.3	11.7	70.3	103	1,166	1,658	22.02	22.02	38.93	7.173	5.43
	130	120	182	172.5	177.3	9.5	57.3	103.8	954	1,665	30.87	30.87	39.09	11.543	3.39
5-inch G. & O. 176503	30	101	183.9	191	187.4	7.1	86.4	103	721	834	1.355	1.369	19.58	.494	39.65
W=22.89 pounds.	50	101	175.5	185.5	180.5	10	79.5	101.2	1,000	1,258	3.674	3.78	29.54	1.012	29.18
A=0.989 square feet.	70	102	177.8	191	184.4	13.2	82.4	103.5	1,351	1,641	7.087	7.162	38.53	2.047	18.82
D=3.25 per cent.	90	104	175	190	182.5	15	78.5	104.5	1,550	1,975	11.64	11.77	46.38	3.736	12.41
	110	108	174.7	190.5	182.6	15.8	74.6	105	1,640	2,198	17.22	17.400	57.61	6.218	8.3
	130	111	174.1	189.3	181.7	15.2	70.7	106	1,592	2,250	23.87	24.14	52.83	9.682	5.46
2-inch G. & O. 176505	30	91	197.8	190.5	194.1	7.3	103.1	105.6	721	699	1.445	1.445	16.41	.271	60.6
W=11.90 pounds.	50	92	190	181	185	9	93	99	834	896	3.964	3.964	21.04	.788	26.71
A=1.00 square foot.	70	95	188	178	183	10	88	101	945	1,062	7.587	7.587	24.94	1.778	14.02
D=6.45 per cent.	90	98	180.4	170.5	175.4	9.9	77.4	100.2	928	1,198	12.42	12.42	28.13	3.445	8.17
	110	101	195.5	183	189.2	12.5	88.2	101	1,182	1,341	18.42	18.42	31.49	5.97	5.28
	130	110	185.2	175.2	180.2	10	70.2	102.2	956	1,362	25.57	25.57	31.98	9.532	3.36
Lamblin radiator	30	92	191.5	181	186.2	10.5	94.3	106.1	[3] 1,114	1,182	1.955	--------	27.75	1.039	26.72
W=66.3 pounds.	50	94	186.2	173	179.6	13.2	85.6	106.4	1,404	1,640	5.614	--------	38.51	2.22	17.35
A=full size.	70	96.5	185	169	177	16	80.5	106.1	1,698	2,110	11.167	--------	49.54	4.144	11.96
D=0.	90	100	179.2	163	171.1	16.2	71.1	106.1	1,719	2,418	18.72	--------	56.77	7.139	7.94
	110	103	187	168	177.5	19	74.5	106.9	2,031	2,729	28.12	--------	64.07	11.477	5.58
	130	109	184.5	166	175.2	18.5	66.3	105.7	1,956	2,950	39.67	--------	69.26	17.564	3.94
Lamblin radiator	30	96	181.4	177	179.2	4.4	83.2	198	871	1,048	1.955	--------	24.61	1.038	23.71
W=66.3 pounds.	50	97	186.5	179.5	183	7	86	199	1,393	1,620	5.614	--------	38.04	2.219	17.15
A=full size.	70	100	184.5	176.	180.2	8.5	80.2	203	1,725	2,150	11.167	--------	50.48	4.144	12.18
D=0.	90	002	181.3	172	176.5	9.3	74.6	205	1,906	2,558	18.72	--------	60.06	7.137	8.43
	110	109	180.8	171.5	176.1	9.3	67.1	200	1,860	2,770	28.12	--------	65.04	11.477	5.67
	130	115	177	168.5	172.7	8.5	57.7	203	1,726	2,990	39.67	--------	70.21	17.564	3.99

[1] W=weight of 1 square foot frontal area of core with water; A=frontal area of core tested; D=percentage. B. t. u. deduction due to header area considered as equivalent to core area.

[2] Note area correction and deduction of percentage due to headers.

[3] Headers were not removed; results not comparable with other tests.

HP. absorbed=$(RV+\frac{1}{6}WV)$ 0.002664, where V=air speed in M. P. H.; R=resistance per unit frontal area-pounds; W=weight of full radiator per unit frontal area—pounds; 6=L/D of airplane—assumed.

HP. dissipated=0.02348×(B. t. u.).

TABLE I.—FIGURE OF MERIT—Continued

Name of radiator with miscellaneous data	Air speed M.P.H.	Temperature in degrees F.						Rate of flow, pounds of water per minute	B. t. u. dissipated per minute for 1 square foot frontal area of core only =C (1)	C per 100° difference between mean water and air	Total resistance of radiator core, in pounds	Total resistance per square foot of frontal area =R	HP. dissipated per 100° difference of temperature per square foot of frontal area =H	HP. absorbed per square foot of frontal area =P	Figure of merit =H/P
		Air in tunnel	Water inlet	Water outlet	Mean	Difference	Mean difference, air and water								
	30	89	185.5	182	183.7	3.5	94.7	298	1,043	1,104	1.955	--------	25.92	1.038	24.95
	50	90	188.3	183	185.6	5.3	95.6	297	1,574	1,646	5.614	--------	38.65	2.219	17.42
	70	93.5	181.2	175	178.1	6.2	84.6	302	1,872	2,215	11.167	--------	52	4.144	12.54
	90	98	180.5	173.5	177	7	79	302	2,114	2,680	18.72	--------	62.93	7.137	8.82
D=0.	110	102	189.5	181	185.2	8.5	83.2	302	2,567	3,085	28.12	--------	72.44	11.477	6.31
	130	108	178	171	174.5	7	66.5	302	2,114	3,180	39.67	--------	74.67	17.564	4.25
Lamblin radiator	30	96.8	179.5	176.5	178	3	81.2	372	1,116	1,374	1.955	--------	32.26	1.038	31.05
W=66.3 pounds.	50	97.7	180	175.8	177.9	4.2	80.2	368	1,546	1,930	5.614	--------	45.32	2.219	20.45
A=full size	70	101.2	178.5	173.4	175.9	5.1	74.7	375	1,913	3,560	11.167	--------	60.11	4.144	14.51
D=0.	90	96.8	183.8	177	180.4	6.8	83.6	378	2,571	3,080	18.720	--------	72.32	7.137	10.13
	110	102.2	180.2	173.2	176.7	7	74.5	368	2,576	3,455	28.120	--------	81.12	11.477	7.06
	140	113	184	177	180.5	7	67.5	367	2,569	3,805	39.67	--------	89.34	17.564	5.08
	30	91	182	177	179.5	5	88.5	102.4	467	528	1.635	1.635	12.39	.251	49.4
2-inc	50	92.5	188.8	182	185.4	6.8	92.9	112	696	749	4.514	4.514	17.59	.801	21.95
	70	95	189.5	180.5	185	9	90	104	854	949	8.757	8.757	22.28	1.913	11.65
	90	97	186	176	181	10	84	102.4	934	1,112	14.42	14.42	26.11	3.818	6.85
	110	105	182.5	173	177.7	9.5	72.7	104.5	907	1,248	21.52	21.52	29.3	6.747	4.35
	140	108	187.5	177.2	182.8	10.3	74.8	101.2	951	1,271	30.17	30.17	29.84	10.969	2.72
5-inch G. & O. 176502	30	96	188.5	182.5	185.5	6	89.5	101	588	657	1.435	1.453	15.43	.44	35.05
W=24.4 pounds.	50	98	185.5	178	181.7	7.5	83.7	100.5	739	883	4.114	4.166	20.73	1.097	18.91
	70	100	183.8	174	178.9	9.8	78.9	101.5	963	1,220	8.157	8.25	28.65	2.297	12.48
	90	103	187	174.5	180.7	12.5	77.7	101.2	1,230	1,584	13.57	13.73	37.19	4.267	8.72
	110	108	184.5	171.5	178	13	70	101.6	1,282	1,832	20.52	20.78	43.02	7.281	5.91
	140	114	185	172	178.5	13	64.5	103.5	1,308	2,029	28.68	29.02	47.64	11.459	4.16

TABLE II.—FIGURE OF MERIT FOR HEINRICH STREAMLINE RADIATOR [1]

Flaps		Temperature in degrees F.: Air in tunnel	Water inlet	Water outlet	Mean	Difference	Mean difference, air and water	Rate of flow, pounds of water per minute	B. t. u. dissipated per minute for 1 square foot of radiating surface=C	C per 100° difference between mean water and air	Total resistance of radiator, in pounds	Total resistance per square foot of radiating surface=R	HP. dissipated per 100° difference of temperature per square foot of radiating surface=H [2]	HP. absorbed per square foot of radiating surface=P [3]	Figure of merit =H/P
		8 by 8 foot tunnel													
	30	100.0	183.0	176.5	179.7	6.5	79.7	358	11.3	14.2	2.483	0.0120	0.333	0.0122	27.3
		98.0	168.0	161.5	164.7	6.5	66.7	366	11.5	17.2			.404		33.1
		98.2	173.0	166.0	169.5	7.0	71.3	364	12.4	16.9			.397		32.5
		98.6	181.0	173.9	177.5	7.1	78.9	363	12.5	15.9			.373		30.6
		99.0	181.0	174.5	177.7	6.5	78.7	362	11.4	14.5			.341		28.0
		99.7	182.2	176.0	179.1	6.2	79.4	362	10.9	13.8			.324		26.6
	50	100.6	183.5	174.5	178.7	9.0	72.7	365	15.9	21.9	7.269	.0353	.515	.0232	22.2
		107.0	184.5	175.5	180.0	9.0	73.0	364	15.9	21.8			.512		22.1
		110.0	185.0	176.0	170.5	9.0	60.5	365	15.9	26.3			.618		26.6
		112.0	186.0	177.0	171.5	9.0	59.5	366	15.9	26.7			.627		27.1
		114.0	187.0	178.1	182.6	8.9	68.6	366	15.8	23.2			.545		23.5
		115.0	187.4	179.2	183.3	8.3	68.3	376	15.1	23.3			.547		23.6
	70	115.0	182.0	173.1	177.6	8.9	62.6	364	15.7	25.2	15.410	.0749	.592	.0397	14.8
		116.0	179.0	170.2	174.6	8.8	58.6	363	15.5	26.5			.623		15.7
		120.0	181.0	171.9	176.5	9.1	56.5	365	16.1	28.5			.669		16.8
		123.0	181.7	173.5	177.6	8.2	54.6	364	14.5	26.6			.625		15.7
		128.0	183.0	175.0	179.0	8.0	51.0	362	14.2	27.9			.655		16.5
		130.0	184.0	176.0	180.0	8.0	50.0	365	14.2	28.5			.670		16.9
		4 by 8 foot tunnel													
Closed	30	90.0	183.0	176.0	179.5	7.0	89.5	370	12.6	14.1	2.483	0.0120	.331	.0122	27.1
		92.0	183.5	176.5	180.0	7.0	88.0	371	12.6	14.3			.336		27.5
		92.1	180.0	173.3	176.7	6.7	84.6	372	12.1	14.3			.336		27.5
		92.2	180.0	173.0	176.5	7.0	84.3	373	12.7	15.1			.355		29.1
		92.5	181.0	174.0	177.5	7.0	85.0	373	12.7	14.9			.350		28.1
		92.5	182.5	175.6	179.0	6.9	86.5	373	12.5	14.5			.341		27.9
	50	94.0	181.5	172.0	176.7	9.5	82.7	377	17.4	21.1	7.269	.0353	.496	.0232	21.4
		94.5	180.2	170.1	175.1	10.1	80.6	376	18.4	22.8			.535		23.1
		95.0	181.1	171.5	176.3	9.6	81.3	376	17.5	21.5			.505		21.8
		95.5	180.0	170.8	175.4	9.2	79.9	376	16.8	21.0			.493		21.3
		96.0	182.0	172.2	177.1	9.8	81.1	376	17.9	22.1			.519		22.3
		96.5	183.7	175.1	179.4	8.6	82.9	376	15.7	19.0			.446		19.3
	70	102.0	184.0	172.0	178.0	12.0	76.0	379	22.1	29.1	15.410	.0749	.684	.0401	17.1
		102.5	184.2	171.8	178.0	12.4	76.5	380	22.9	30.0			.705		17.6
		103.0	183.0	171.0	177.0	12.0	74.0	379	22.1	29.9			.702		17.5
		103.5	181.2	169.1	175.1	12.1	71.6	378	22.2	31.0			.727		18.1
		104.0	181.2	169.5	175.3	11.7	71.3	378	21.5	30.2			.709		17.7
		104.5	180.7	169.8	175.3	10.9	70.7	378	20.0	28.3			.665		16.6
	90	106.1	180.1	167.5	173.8	12.6	67.7	378	23.1	34.2	25.950	.1260	.803	.0638	12.6
		108.0	180.0	167.1	173.6	12.9	65.6	380	23.8	36.3			.852		13.4
		108.4	179.2	166.5	172.8	12.7	64.4	381	23.5	36.5			.858		13.4
		110.0	179.0	167.0	173.0	12.0	63.0	381	22.2	35.3			.829		13.0
		111.3	179.8	168.0	173.9	11.8	62.6	381	21.8	34.8			.818		12.8
		111.6	181.7	169.1	175.4	12.6	63.8	380	23.3	36.6			.859		13.5
	110	114.0	182.0	169.3	175.6	12.7	61.6	377	23.3	37.8	39.650	.1926	.888	.0976	9.1
		116.2	182.0	169.9	175.8	12.1	59.6	378	22.2	37.3			.876		9.0
		118.0	181.7	170.0	175.8	11.7	57.8	392	22.3	38.6			.907		9.3
		119.3	181.5	170.0	175.7	11.5	56.4	393	22.0	39.0			.916		9.4
		120.3	182.0	171.0	176.5	11.0	56.3	393	21.0	37.3			.876		9.0
		120.2	183.0	171.8	177.4	11.2	57.2	392	21.3	37.3			.876		9.0
	130	114.1	178.0	164.1	171.1	13.9	57.0	384	25.9	45.5	56.750	.2755	1.068	.1437	7.4
		118.2	186.0	170.0	178.0	10.0	59.8	385	29.9	50.0			1.173		8.2
		121.1	184.2	172.2	178.2	12.0	57.1	385	22.4	39.3			.923		6.4
		124.0	182.0	170.2	176.1	11.8	52.1	385	22.1	42.5			.999		6.9
		126.3	181.2	169.9	175.6	11.3	49.3	385	21.1	42.8			1.005		7.0
		128.4	181.5	171.0	176.2	10.5	47.8	386	19.7	41.3			.970		6.7
Open	130	100.0	184.2	176.0	180.1	8.2	81.1	388	15.4	19.2	------	------	------	------	------
		104.0	180.7	172.5	176.6	8.2	72.6	385	15.3	21.1					
		108.0	182.2	174.0	178.1	8.2	70.1	390	15.5	22.1					
		112.0	182.0	175.2	178.6	7.8	66.6	387	14.6	21.9					
		114.0	182.5	176.0	179.2	6.5	65.2	388	12.2	18.7					
		116.0	182.7	176.5	179.6	6.2	63.6	388	11.7	18.4					

[1] Supplied data: Radiating surface=206 square feet. Weight of radiator, dry=113 pounds; weight of radiator, full=173 pounds.

[2] Horsepower dissipated=0.02348×(B. t. u.).

[3] Horsepower absorbed=0.002664 $(R V+1/6\ W V)$ where V=air speed in M. H. P. R=resistance per square foot of radiating surface—pounds. W=weight of full radiator per square foot of radiating surface—pounds. 6=L/D of airplane—assumed.

Table III.—FIGURE OF MERIT FOR HEINRICH WING RADIATOR NO. 1[1]

[9 fins, 1-inch pitch]

Air speed M. P. H.	Temperature in degrees F.: Air in tunnel	Water inlet	Water outlet	Mean	Difference	Mean difference air and water	Rate of flow in pounds of water per minute	B. t. u. dissipated per minute per square foot of [illegible]	C per 100° difference between water and air	Total resistance of radiator in pounds[2]	Total resistance per square foot of radiating surface $=R$	HP. dissipated per 100° difference of temperature per square foot of radiating surface $=H$[3]	HP. absorbed per square foot of radiating surface $=P$[4]	Figure of merit $=H/P$
	90.0	181.8	180.0	180.9	1.8	90.9	217	20.2	22.2			0.519		22.8
	90.0	182.2	180.2	181.5	2.0	91.5	217	21.4	23.4			.549		24.1
	90.0	182.3	180.5	181.4	1.8	91.4	212	19.7	21.6			.507		22.2
50	90.0	182.7	180.8	181.8	1.9	91.8	213	20.9	22.8	0.686	0.0355	.535	0.0228	23.5
	90.5	183.0	181.0	182.0	2.0	91.5	217	22.4	24.5			.575		25.2
	90.5	183.0	181.2	182.1	1.8	91.6	217	20.2	22.1			.519		22.8
	92.0	182.7	180.5	181.6	2.2	89.6	217	24.7	27.6			.648		17.2
	92.5	182.4	180.1	181.3	2.3	88.8	213	25.3	28.5			.669		17.8
	93.0	182.2	179.9	181.1	2.3	88.1	213	25.3	28.8			.677		18.0
70	93.5	181.8	179.6	180.7	2.2	86.7	217	24.7	28.5	1.275	.0659	.669	.0376	17.8
	94.0	181.5	179.4	180.5	2.1	86.5	218	23.7	27.4			.643		17.1
	94.5	181.0	179.0	180.0	2.0	85.5	219	22.6	26.4			.620		16.5
	96.0	180.7	178.2	179.5	2.5	83.5	219	28.3	33.9			.796		13.8
	97.0	180.3	177.8	179.1	2.5	82.1	217	28.0	34.2			.803		13.9
	98.0	180.4	177.9	179.2	2.5	81.2	217	28.0	34.6			.813		14.1
90	99.5	180.7	178.2	179.5	2.5	80.0	211	27.3	34.1	2.030	.1049	.801	.0577	13.9
	[illegible]	181.0	178.5	179.8	2.5	79.3	212	27.4	34.6			.813		14.1
	[illegible]	180.9	178.5	179.7	2.4	78.7	212	26.3	33.4			.785		13.6
	[illegible]	181.0	178.5	179.8	2.5	73.8	217	28.0	38.0			.893		10.6
	[illegible]	181.1	178.6	179.9	2.5	72.4	217	28.0	38.7			.909		10.8
1[illegible]	[illegible]	181.0	178.5	179.8	2.5	70.8	217	28.0	39.6	2.935	.1517	.930	.0843	11.0
	[illegible]	180.8	178.3	179.6	2.5	70.1	217	28.0	40.0			.939		11.1
	[illegible]	180.8	178.3	179.6	2.5	69.6	217	28.0	40.3			.946		11.2
	[illegible]	181.0	178.5	179.8	2.5	69.3	219	28.3	40.9			.961		11.4
	[illegible]	180.9	178.4	179.7	2.5	62.7	219	28.3	45.2			1.061		8.9
	[illegible]	181.0	178.5	179.8	2.5	61.3	219	28.3	46.2			1.083		9.1
1[illegible]	[illegible]	180.9	178.5	179.7	2.4	59.7	217	26.9	45.1	4.000	.2068	1.058	.1187	8.9
	[illegible]	181.0	178.8	179.9	2.2	58.4	219	24.9	42.6			1.000		8.4
	[illegible]	181.2	179.0	180.1	2.2	56.6	219	24.9	44.0			1.033		8.7
	[illegible]	181.4	179.2	180.3	2.2	55.3	219	24.9	45.1			1.058		8.9
	112.0	183.0	180.2	181.6	2.8	69.6	219	31.7	45.6			1.070		7.7
	117.0	182.8	180.0	181.4	2.8	64.4	217	31.4	48.8			1.146		8.2
	122.0	182.2	179.8	181.0	2.4	59.0	217	26.9	45.6			1.070		7.7
140	125.0	182.2	180.0	181.1	2.2	56.1	217	24.7	44.0	4.580	.2363	1.033	.1388	7.4
	127.5	182.4	180.2	181.3	2.2	53.8	213	24.2	45.0			1.057		7.6
	129.0	182.6	180.5	181.6	2.1	52.6	213	23.1	43.9			1.030		7.4

[1] Weight of radiator, dry =10.90 pounds; weight of radiator, wet=15.78 pounds. Radiating surface=19.35 square feet.
[2] Faired resistance values.
[3] HP. dissipated=0.02348×B. t. u.
[4] HP. absorbed=0.002664 ($RV+\frac{1}{6}WV$). V=air speed in M. P. H. R=resistance per square feet. of radiating surface in pounds. W=weight of full radiator per square foot of radiating surface in pounds. $6=L/D$ of airplane, assumed.

TABLE IV.—FIGURE OF MERIT FOR HEINRICH WING RADIATOR NO. 3[1]

[6 Fins, 1¼" pitch]

Air speed M.P.H.	Temperature in degrees F.: Air in tunnel	Water inlet	Water outlet	Mean	Difference	Mean difference, air and water	Rate of flow in pounds of water per minute	B. t. u. dissipated per minute per square foot of radiating surface C	C per 100° difference between mean water and air	Total resistance of radiator in pounds[2]	Total resistance per square foot of radiating surface =R	HP. dissipated per 100° difference of temperature per square foot of radiating surface =H[3]	HP. absorbed per square foot of radiating surface =P[4]	Figure of merit =H/P
50	87.0	175.5	173.8	174.7	1.7	87.7	161	21.2	24.2	0.493	0.0382	0.568	0.259	21.9
	87.0	176.9	175.1	176.0	1.8	89.0	155	21.6	24.3			.571		22.1
	87.5	180.6	179.1	179.9	1.5	92.4	155	18.0	19.5			.458		17.7
	88.0	180.0	178.6	179.3	1.4	91.3	158	17.2	18.8			.441		17.0
	88.0	180.9	179.3	180.1	1.6	92.1	158	19.6	21.3			.500		19.3
	88.5	182.1	180.4	181.2	1.7	91.9	158	20.8	22.6			.531		20.5
70	90.0	183.3	181.0	182.2	2.3	92.2	155	27.7	30.1	.917	.711	.707	.0425	16.6
	90.5	183.9	181.7	182.8	2.2	92.3	155	26.5	28.7			.674		15.9
	91.0	183.8	181.5	182.7	2.3	91.7	155	27.7	30.2			.709		16.7
	91.5	183.7	181.5	182.6	2.2	91.1	151	25.8	28.3			.664		15.6
	92.0	183.6	181.3	182.5	2.3	90.5	155	27.7	30.6			.719		16.9
	92.5	183.0	180.9	182.0	2.1	89.5	155	25.2	28.2			.662		15.6
90	94.5	182.4	179.9	181.2	2.5	86.7	155	30.1	34.7	1.459	.1131	.815	.0646	12.6
	96.0	181.9	179.4	180.7	2.5	84.7	155	30.1	35.6			.836		12.9
	97.0	181.2	178.8	180.1	2.4	83.1	155	28.9	34.8			.817		12.6
	97.5	180.6	178.2	179.5	2.4	82.0	155	28.9	35.3			.829		12.8
	98.0	180.4	178.0	179.3	2.4	81.3	155	28.9	35.6			.836		12.9
	98.5	180.0	177.0	178.3	3.0	79.8	151	35.2	44.1			1.035		16.1
110	102.0	180.0	177.2	178.6	2.8	76.6	155	33.7	44.0	2.114	1.639	1.033	.939	11.0
	103.5	179.5	177.0	178.3	2.5	74.8	155	30.1	40.3			.946		10.1
	104.5	179.0	176.7	177.9	2.3	73.4	155	27.7	37.8			.887		9.4
	106.0	179.0	176.5	177.8	2.5	71.8	155	30.1	41.9			.984		10.5
	107.5	178.8	176.3	177.6	2.5	70.1	155	30.1	43.0			1.010		10.8
	108.5	178.6	176.2	177.4	2.4	68.9	155	28.9	42.0			.986		10.5
130	112.5	179.5	176.8	178.2	2.7	65.7	155	32.5	49.5	2.879	.2231	1.162	.1315	8.8
	115.0	182.0	179.1	180.6	2.9	65.6	155	34.9	53.2			1.248		9.5
	119.0	183.2	180.5	181.9	2.7	62.9	155	32.5	51.7			1,214		9.2
	120.5	184.4	181.8	183.1	2.6	62.6	155	31.3	50.0			1.173		8.9
	122.0	183.7	181.3	182.5	2.4	60.5	155	28.9	47.8			1.122		8.5
	124.0	183.7	181.3	183.5	2.4	59.5	148	28.9	48.6			1.141		8.7
140	127.0	184.4	182.0	183.2	2.4	55.2	155	28.9	52.4	3.290	.2550	1.230	.1535	8.0
	130.0	184.6	182.1	183.4	2.5	53.4	144	27.9	52.3			1.228		8.0
	132.0	185.0	182.6	183.8	2.4	51.8	158	29.4	56.8			1.333		8.7
	133.5	185.8	183.5	184.7	2.3	51.2	158	28.2	55.1			1.293		8.4
	135.5	185.9	183.9	184.9	2.0	49.4	158	24.5	49.6			1.154		7.5
	137.0	185.8	183.9	184.9	1.9	47.9	158	23.3	48.7			1.143		7.4

[1] Weight of radiator, dry=8.03 pounds, weight of radiator, wet=12.09 pounds. Radiating surface=12.90 square feet.
[2] Faired resistance values.
[3] HP. dissipated=0.02348×B.t.u.
[4] HP. absorbed=0.002664 $(RV+\frac{1}{6}WV)$. V=air speed in M.P.H. R=resistance per square foot of radiating surface in pounds. W=weight of full radiator per square foot. of radiating surface in pounds. $6=L/D$ of airplane, assumed.

TABLE V.—FIGURE OF MERIT FOR CURTISS RADIATOR[1]

[Shutter open]

Air speed (M. P. H.)	Total resistance of radiator[2] (pounds)	HP. dissipated per 100° of temperature =H[3]	HP. absorbed=P	Figure of merit of =H/P
30	6.11	56.91	2.62	21.71
50	16.50	99.39	5.74	17.31
70	31.43	141.45	10.84	13.05
90	51.05	175.44	18.63	9.42
110	75.19	197.22	29.87	6.61
130	103.79	217.65	45.21	4.81

[1] Weight of radiator, dry=105.6 pounds; wet=159.8 pounds; frontal core area=3 square feet.
[2] Resistance values were computed from faired curve.
[3] Values for H were taken from 9-inch tests in Report No. 183, and increased in proportion to the change in core area, neglecting effect of header area.

TABLE VI.—WATER-PRESSURE DROP INSIDE RADIATOR FOR DIFFERENT RATES OF FLOW

[Pressure head—inches of water]

Water flow pounds per minute	U. S. Cartridge, 9-inch	U. S. Cartridge, 4-inch	G. & O. 176504	Rome Turney	G. & O. 176503	G. & O. 176507	G. & O. 176506	G. & O. 176505	G. & O. 17502
40	2.38	2.52	1.80	2.65	1.55	1.60	2.47	6.0	1.62
60	5.05	5.45	3.86	5.65	3.45	3.60	5.55	13.5	3.48
80	8.62	9.35	6.60	9.75	6.10	6.45	9.90	24.0	6.00
100	13.10	14.25	10.00	14.80	9.50	10.10	15.50	37.5	9.10
120	18.40	20.10	14.00	21.00	13.60	14.50	22.40	54.0	12.90
140	24.50	27.00	18.80	28.00	18.60	20.00	30.50	73.8	17.20
160	31.50	34.50	24.00	36.00	24.20	26.00	39.50	96.0	22.00
180	39.30	43.00	29.80	44.80	30.50	33.00	50.00		

FOR LAMBLIN RADIATOR

Water flow	125	150	175	200	250	300	350	400	450
Pressure drop	15.3	21.9	30.0	38.8	60.5	87.0	118	145	195

TABLE VII.—PRESSURE DROP IN RADIATOR FOR VARIOUS RATES OF FLOW

Rate of flow in pounds of water[1] per minute	Pressure drop in radiator in inches of mercury
HEINRICH RADIATOR NO. 1 (9 FINS, 1-INCH PITCH)	
0	0
145	2.60
189	4.00
224	5.45
248	6.80
HEINRICH RADIATOR NO. 3 (6 FINS, 1½-INCH PITCH)	
0	0
84	1.90
120	3.26
155	5.40
168	6.14
189	7.60
216	9.50

[1] Temperature of water=180° F.